Field Trip

to the

BHP / San Manuel Mine

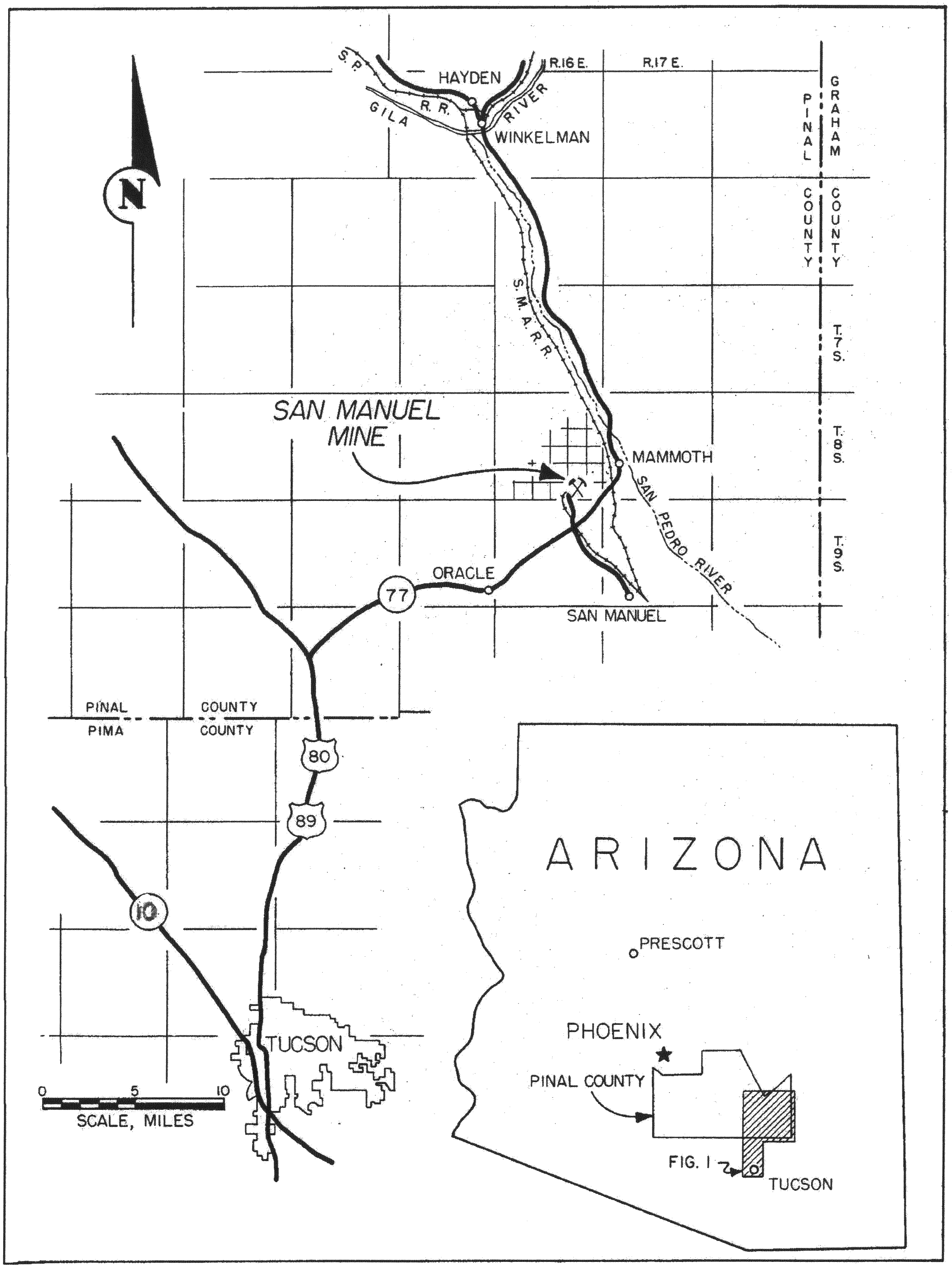
Pinal County, Arizona

Interstate Technical Group on Abandoned Underground Mines Fifth Biennial Workshop

Thursday, April 22

The tour will be led by:

Jeff Parker, BHP Copper San Manuel Operations,
Corolla Hoag, SRK Consulting
Nick Priznar, Arizona Department of Transportation
Jon Spencer, Arizona Geological Survey,
Lou Sandbak, Geologist/ Engineer, Grupo Mexico/ASARCO, Ray Arizona
Walter Douglas Chief Development Engineer (Ret.) Magma Copper Company
L. A. Thomas, Chief Geologist (Ret.) Magma Copper Company



Location Map, San Manuel Mine.

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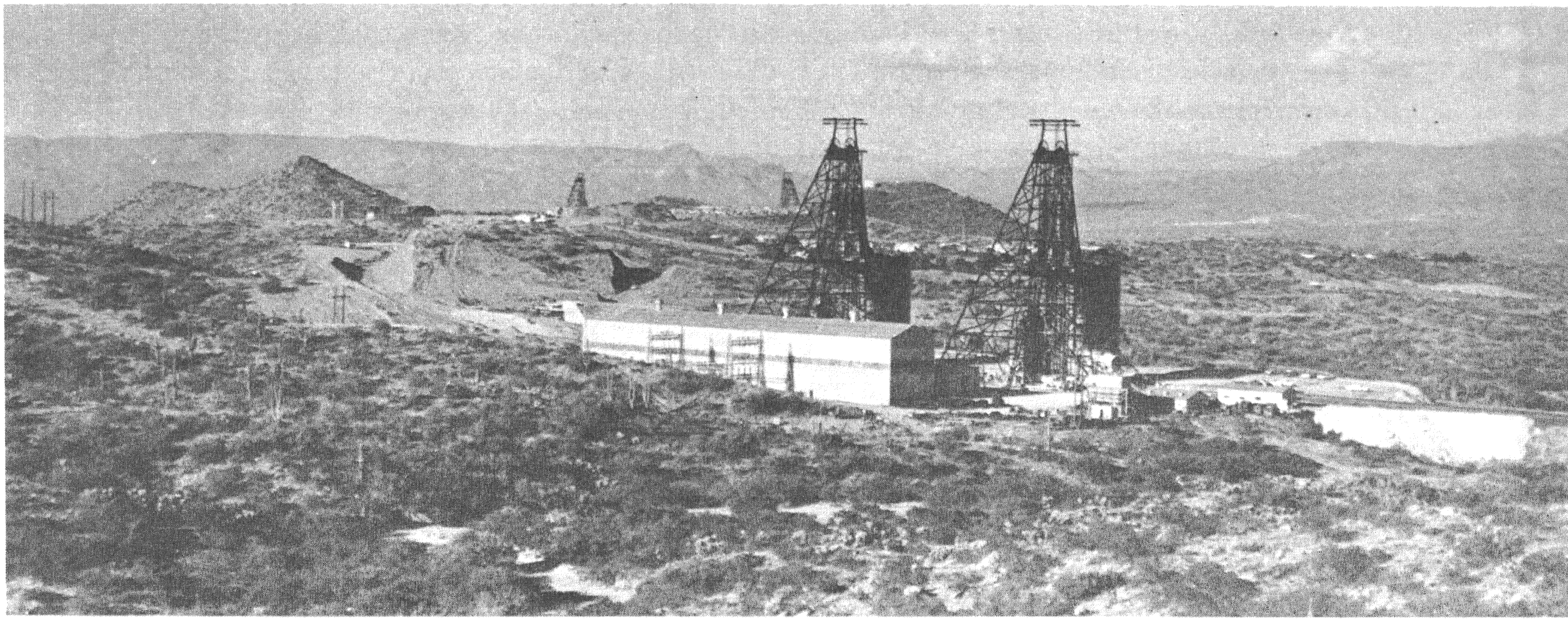
The Catalina Mountains are the backdrop for this half-day tour of the BHP Copper San Manuel Mine and surrounding area. The first stops will provide a regional overview of the Catalina Mountains, Pirate Fault, Black Hills, and the San Pedro Valley. The group will then visit the mine, which is located 35 miles northwest of Tucson and is now in the process of closure and reclamation. The copper mine metamorphosed over its long life from an underground operation (2 units) to an open pit, and later as a modern in-situ leaching operation. (See Aerial Photos in Appendix)

Mining History

Prospecting and exploration at San Manuel and the nearby Tiger Mine began in the 1880s. Early development of the San Manuel underground mine began in March 1948 with the sinking of the No. 1 Shaft. Five shafts were subsequently sunk in the years between 1948 and 1953, and drift development began on the 1415 Production Level in 1952. The block caving method was used to undercut the ore. By 1956, a plant site and town site were established at San Manuel with a railroad connecting the mine and plant. By the early 1970s, the mine and mill had reached a production of 58,000 tons per day; the copper sulfide ore was extracted from six grizzly (production) levels extending 2675 feet below ground surface (bgs). In 1973, the 25-foot diameter No. 5 Shaft was completed to a depth of 3,910 feet bgs and was designed to service the lower portion of the ore body known as the Kalamazoo Mine. The underground operation set a world record by hoisting more than 702 million tons of ore to the surface. Meanwhile, the open pit-heap leach operation began in 1984 to mine the copper oxide ore. Simultaneous in-situ solution mining occurred in portions of the pit; weak sulfuric acid solution was gravity injected into the oxide zone via injection wells from 1985 to 1999. The acid solutions mobilized the copper into solution, which was then extracted by nearby production wells or collected in the underground mine and pumped to a solvent-extraction electrowinning facility at the mine site.



.—Principal surface installations at the San Manuel mine. The two ore hoisting shafts, 3A (left) and 3B (right), are in the foreground. No. 4 shaft is beyond the left edge of No. 3A shaft in the middle distance. No. 1 shaft is to the left of No. 4 shaft. Red Hill, in the middle distance, is viewed between No. 3A and 3B shafts. The Collins vein in the St. Anthony deposit crops out in the saddle between the twin peaks to the left of No. 1 shaft in the middle distance.

The block caving method was used at several Arizona mining operations including Bisbee, Miami, San Manuel, and Morenci. As the ore is broken and pulled through the draw points, tension cracks develop in the column of rock and a funnel-shaped depression or pipe begins to form. The orientation of the ore zone, extraction method, rock mass properties of the host rocks, and the existence of dominant structures such as through-going faults dictate the eventual slope angles and shape of the subsidence zone. At San Manuel, there was little difficulty passing caved ore through the 11-inch grizzlies, while the San Manuel Formation (conglomerate) tended to break into large masses having lateral dimensions of 20-30 feet. The group will have a dramatic view of these large blocks from the pit overview stop. The first subsidence fractures in the surface were noted in 1956 after three months of production. Elliptical shapes developed into larger, circular to polygonal-shaped subsidence features. Major escarpments started to develop on the south and west side of the area above the workings as the rocks subsided into small stair-steps and pulled away from the intact ground. On the south edge of the pit, a vertical bank more than 100 feet high of San Manuel Formation has held a 2-degree overhang for many years with minimal raveling or decrease in the slope angle.

Changes in Highway Alignment

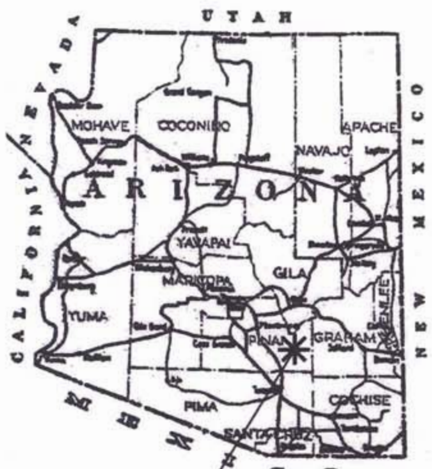
Oracle Highway (Hwy 77) had a long history connecting the nearby Tiger mining camp via stagecoach and wagon with the closest railroad shipping point in Tucson. The old highway (Tiger Mine Road) allowed access between the villages of Oracle and Tiger, the Tiger Mine, and the village of Mammoth, where water for people, livestock, and milling operations was readily available.

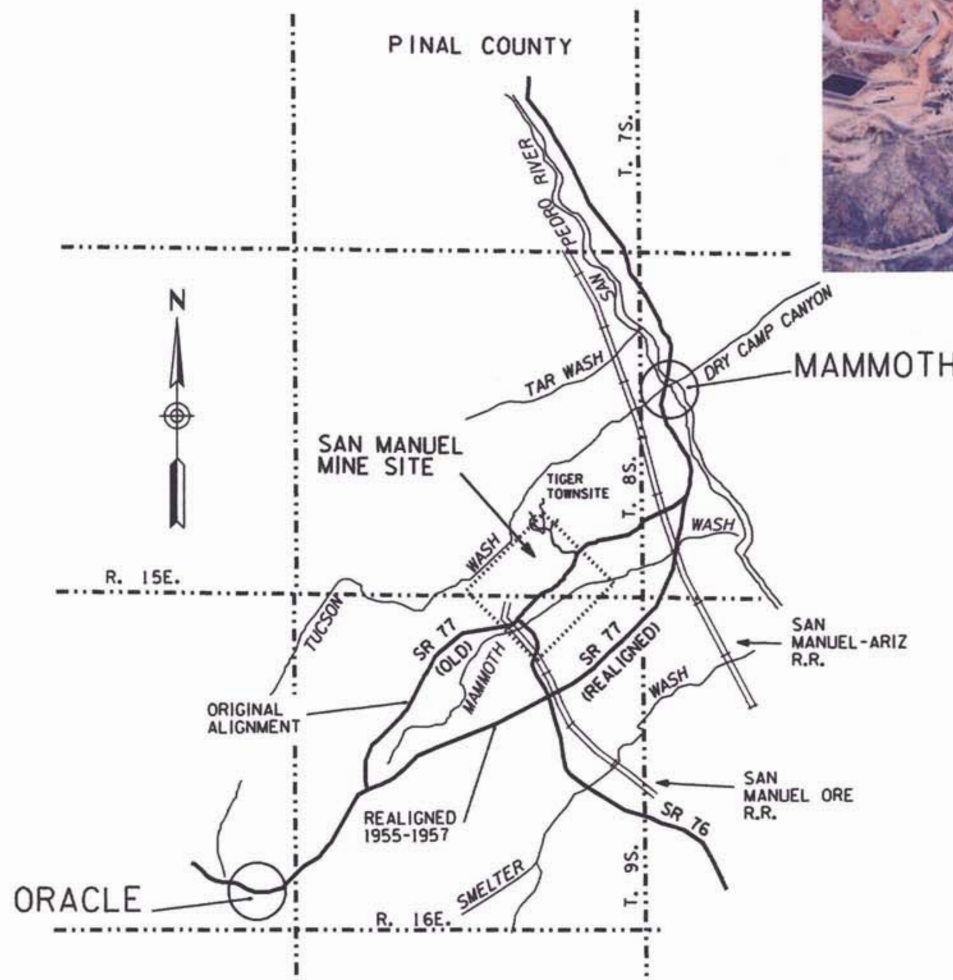
In 1952 the Magma Copper obtained a $94,000,000.00 loan from the U.S. Reconstruction Finance Corporation to develop the San Manuel property. One requirement for the loan approval was to construct a townsite nearby to accommodate workers and their families.

At the time copper mining by block- caving techniques was an accepted facet of the copper mining. However rock mechanic experts were unable to predict the ultimate geometry of the block caved subsidence zone. This fact combined with the positive economic state-wide impact of developing the mine in 1955, led to the decision to realign SR 77, to facilitate mining the deposit. The San Manuel subsidence zone and open pit now has consumed part of that old alignment.

Magma Copper Corporation worked with state transportation officials to develop an alternate route between Oracle and Mammoth. Later as the town site of San Manuel was established, the road was developed into a state highway connecting the tri-community area. As underground subsidence from the Kalamazoo Mine began in the 1980s and 1990s, subsidence cracks developed to the southwest of the surface facilities and eventually impacted a commercial operation for crushed rock materials.

Several highway construction projects were awarded to by-pass the mine area and to connect the mine with the community of San Manuel. Starting in 1955 Projects S-358 (3) S-358 (2) & S-358 (1), constructed SR 76 by connecting the community of San Manuel to a new intersection on old SR 77, 2 miles south of Tiger. Approximately two miles northeast of Oracle Arizona, Projects S253 (3), and SG 253(4), S253 (7) & S253 (8) realigned SR77, for 8 miles in a northeasterly curving route, bypassing the proposed mining facility. Highway construction was completed by 1957.





(NOT TO SCALE)

SAN MANUEL MINE SITE

(RECENT PHOTO)

ARIZONA DEPARTMENT OF TRANSPORTATION
INTERMODAL TRANSPORTATION DIVISION
MATERIALS GROUP

FIELD TRIP
LOCATION MAP

GEOTECHNICAL SECTION		DATE
DESIGN	N. PRIZNAR	04/04
DRAWN	D. CHOYE[illegible]	[illegible]4/04
CHECKED	N. PRIZNA[illegible]	[illegible]4/04

GEOLOGY

Southeastern Arizona is the center of what is perhaps the largest concentration of copper ore bodies on Earth. About two dozen porphyry-copper deposits present in this area have yielded much of the world's copper during the past 100 years. These deposits are mostly between 75 and 55 million years old, and were produced by porphyritic magmatic intrusions. The San Manuel ore body is one of these porphyry-copper deposits.

Tucson and surrounding areas, including the San Manuel mine area, are within the Basin and Range province, and area characterized by numerous small mountain ranges separated by small but deep sedimentary basins. The Basin and Range province covers southern and western Arizona as well as southern New Mexico, Nevada, western Utah, and much of northern Mexico. This area had a much different topography before the Earth's crust was stretched and broken into fault blocks separated by normal faults. Fault blocks that were uplifted now form mountain ranges and those that were down-dropped underlie the basins. This crustal extension and faulting occurred largely between about 35 and 10 million years ago, but is still occurring in some areas. The Tucson basin, Santa Catalina Mountains, and San Pedro Valley are each fault blocks within the Basin and Range province

The San Manuel fault is a normal fault that was active during Basin and Range extension. This fault broke the San Manuel ore body into two halves, and separated them by 1-2 kilometers. The upper fragment, displaced down and to the west, is known as the Kalamazoo ore body.

BLOCK CAVNG PROCESS

Abstraced from (Sandbak & Alexander 1995)

Mine Development utilized a full-gravity block caving method of mining modeled directly after the systems used at Miami, Arizona. The system consisted of a draw level, a haulage level, and a smaller undercut level. The undecut level, located approximately 18 feet above the draw level, is where caving was initiated by drilling and heavy blasting. After rock was caved, it was funneled into draw raises that guide it to draw points on the draw level. The ore was then pulled from the draw points located within the grizzly lines by chute tappers using various tools. The chute tappers feed ore through galleries into raises that lead to the haulage level 60 feet below. On the haulage level the ore was drawn from the raises by a car loader, put onto cars, hauled to the dumps, and hoisted to the surface.

The production levels are divided into panels and the panels were the subdivided into blocks. The blocks usually consist of 3 to 5 grizzly lines on either 35 or 40-foot centers. The grizzly lines are 140 feet long. Within a convention grizzly drift there are 16 draw points servicing 8 grizzlies and raises. This layout controls the draw point spacing (either 17.5 by 17.5 feet or 20 by 17.5 feet) as well as the haulage spacing where panel drifts are on 75- foot centers and raise stations are on either 35 or 40 foot centers.

Geology Notes for the San Manuel Area

Abstracted From: Sandbak and Alexander, Geology and Rock Mechanics of the Kalamazoo Orebody, San Manuel, Arizona *in* AGS Digest Volume 20, Geology of the Porphyry Copper Deposits.

Oracle Granite
Proterozoic (1.4 billion year old) coarse-grained biotite granite with large phenocrysts of potassium feldspar.

Diabase
Two distinct occurrences are found in the San Manuel area.
Younger dikes are up to ten feet wide and are irregular, whereas older dikes are typically 150 - 200 feet wide. They range in color from red to black, and are usually hard and massive. Its texture is aphanitic to subophitic, and is composed of fine needle-like crystals of plagioclase and pyroxene.

Monzonite or **Granodiorite Porphyry**
Late Cetaceous monzonite porphyry, which is highly altered close to San Manuel. Fresh unaltered granodiorite porphyry is medium to light gray in color and composed of zoned plagioclase phenocrysts that make up 15 - 50 percent of the rock in a very fine-grained matrix of quartz and orthoclase.

Dacite Porphyry
Similar to the above rock but is usually dark gray to black in color and has fresh plagioclase phenocrysts that average 10 to 20 percent of the rock mass.

Igneous Breccia
A very hard rock material consisting mostly of quartz monzonite with lesser amounts of granodiorite porphyry.

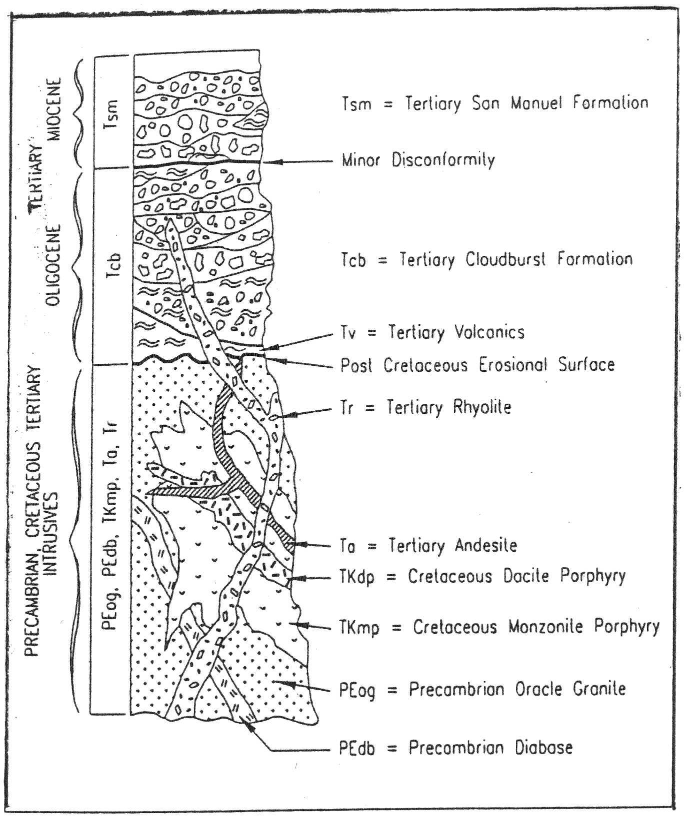
Andesite or **Andesite Porphyry**
Mid-Tertiary andesite typically forming small dikes averaging 5 to 20 feet thick along fault zones. It is very fine-grained and dark gray green to dark gray in color.

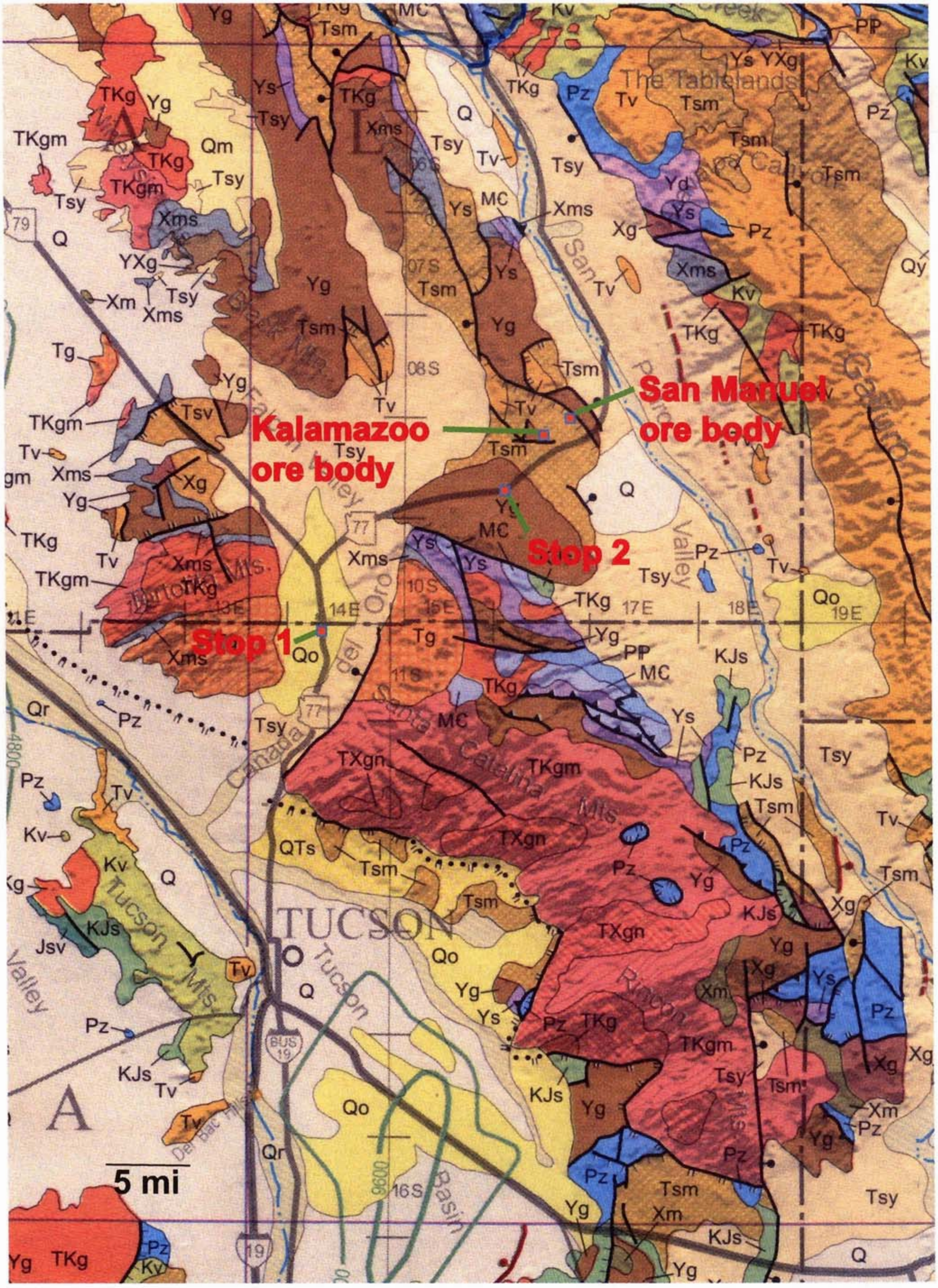
Cloudburst Formation
Consists of up to 5770 feet of interlayer conglomerate, sedimentary breccia, and volcanic rocks. The formation consists of two units: A lower volcanic unit consisting of andesitic lava flows and tuffs (3,900-4,900 ft thick) and an upper fanglomerate unit.

Rhyolite
The youngest rock to intrude the local ore bodies cuts all the older rocks types including the Cloudburst Formation. It is very fine grained and ranges from pink to greenish gray. In some case displays distinct flow banding.

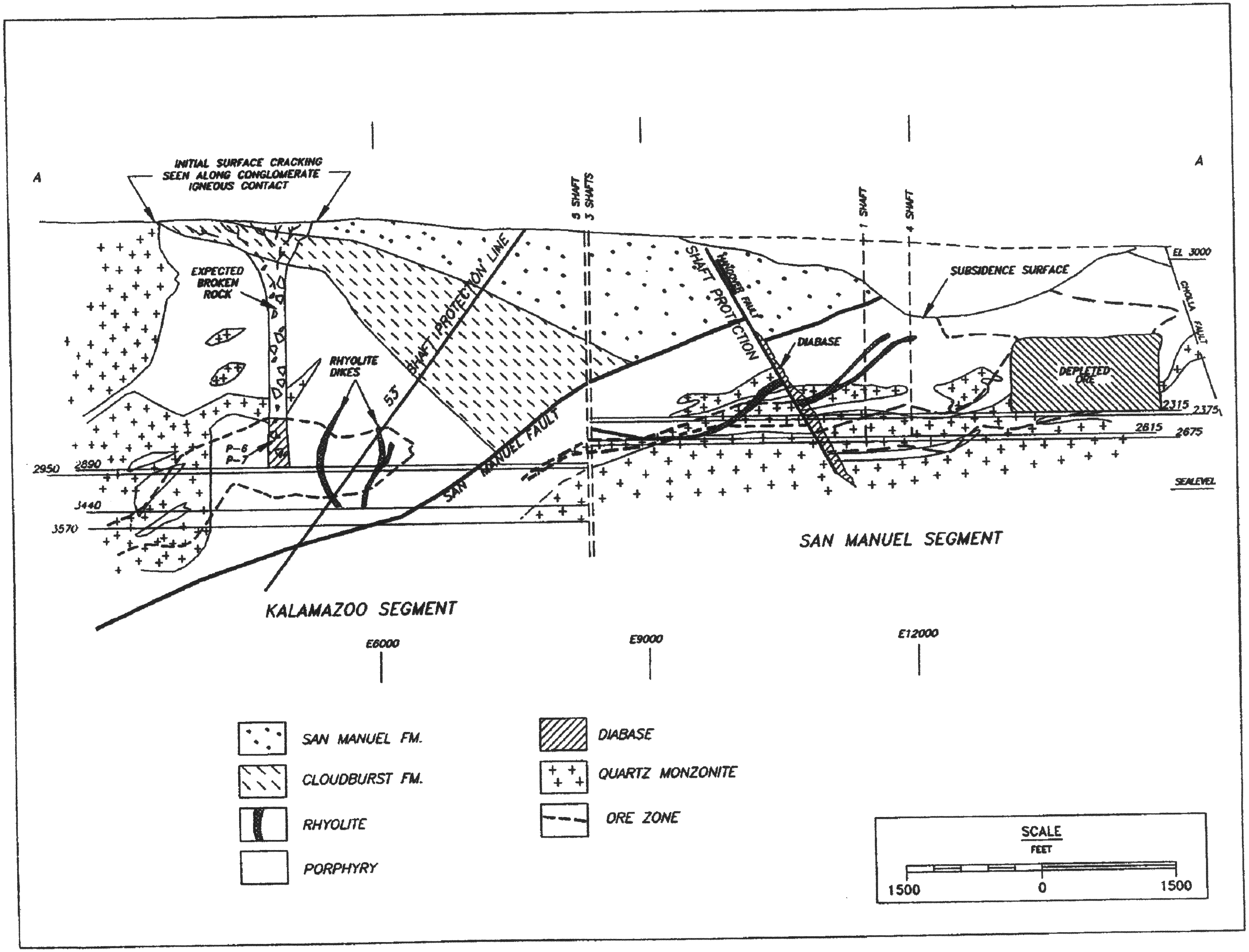
San Manuel Formation

Weakly to moderately consolidated, reddish brown to light gray conglomerates with cobbles and boulders of light gray quartz monzonite, rhyolite, monzonite, diabase, and other basic rocks. This unit is nearly 4,000 feet thick in the Mammoth Area. The formation strikes N35°W to N50°W and dips approximately 30° to 40° NE.

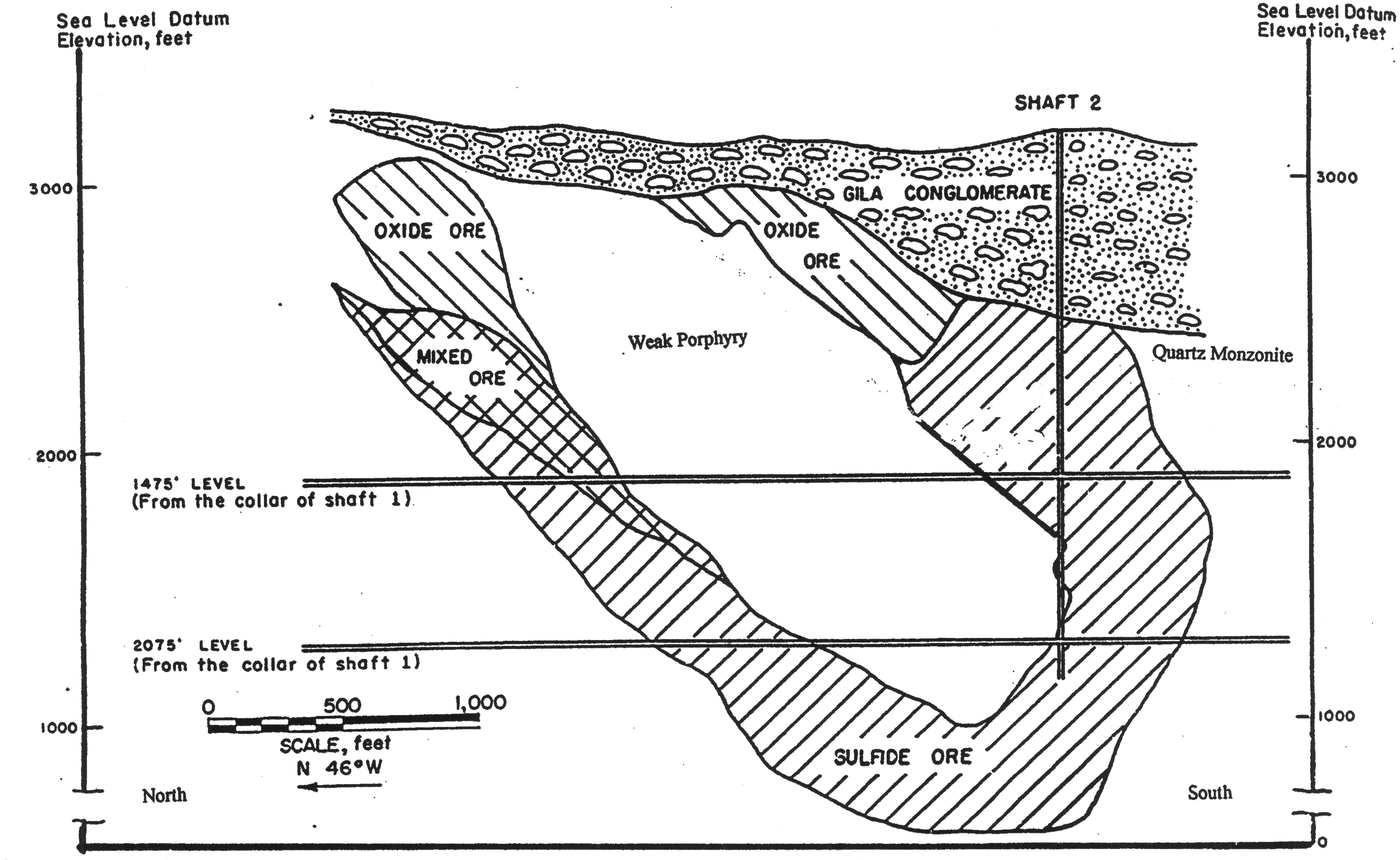




San Manuel ore body
Kalamazoo ore body
Stop 1
Stop 2
5 mi
TUCSON
The Tablelands
Santa Catalina Mts.
Rincon Mts.
Tucson Mts.
Tortolita Mts.
Cañada del Oro
San Pedro Valley
Galiuro
Tucson Basin
Avra Valley
Del Bac Hills

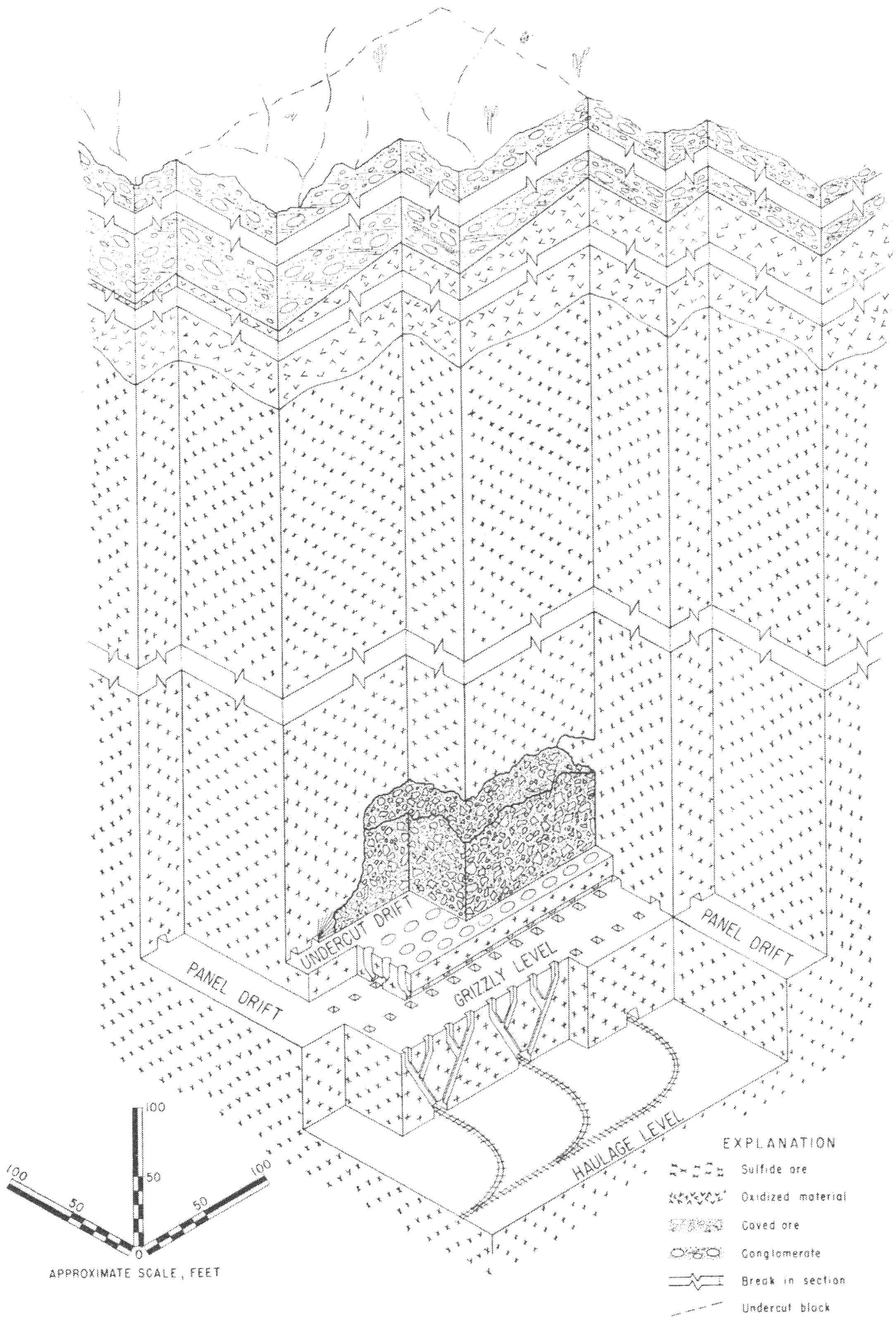


Generalized longitudinal section through the San Manuel-Kalamazoo Porphyry Copper Deposit.


Sea Level Datum
Elevation, feet
3000
2000
1000
SHAFT 2
GILA CONGLOMERATE
OXIDE ORE
OXIDE ORE
MIXED ORE
Weak Porphyry
Quartz Monzonite
1475' LEVEL
(From the collar of shaft 1)
2075' LEVEL
(From the collar of shaft 1)
0
500
1,000
SCALE, feet
N 46°W
SULFIDE ORE
North
South
Sea Level Datum
Elevation, feet
3000
2000
1000
0

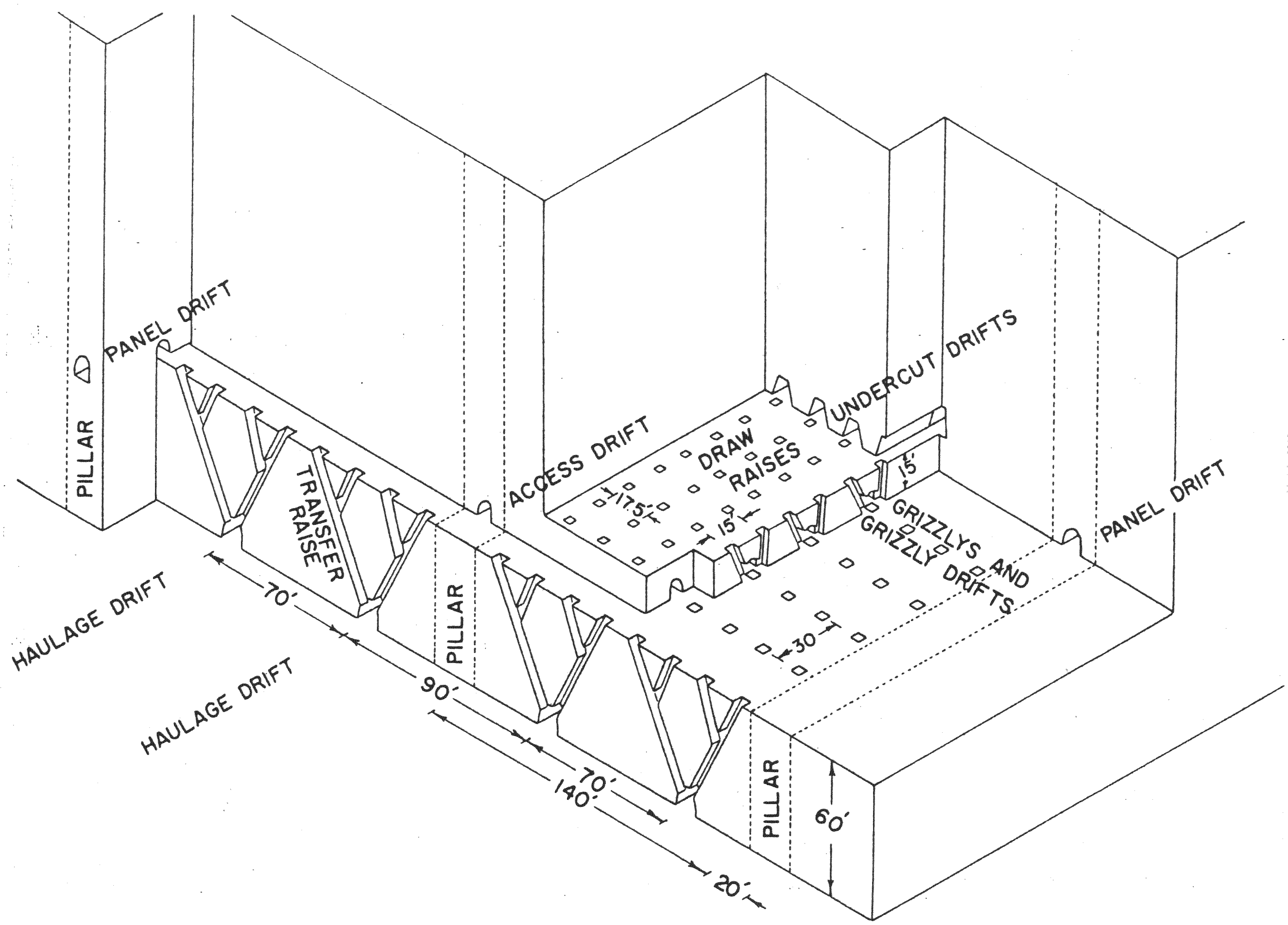
Block Caving Mining Diagrams

The following graphics have been abstracted to display the methods of underground block caving methods utilized at San Manuel

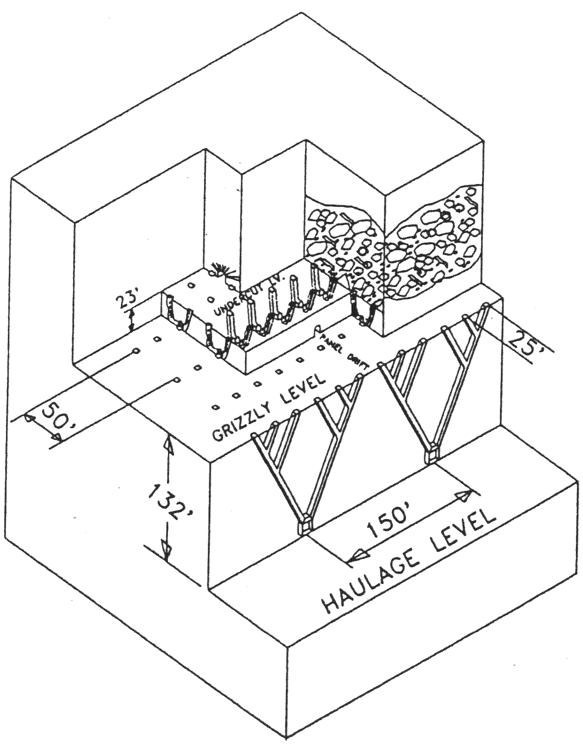


Generalized Diagram Of A Block Caving Method

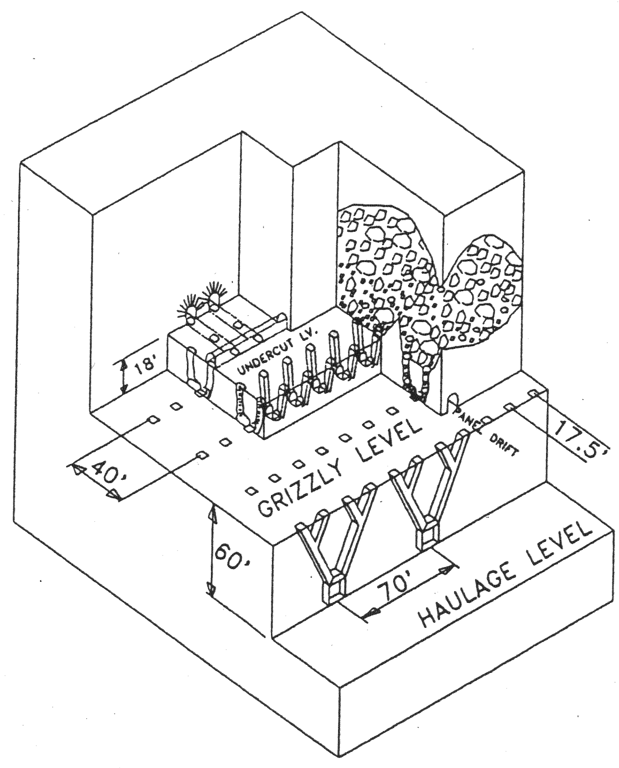
From: U.S Bureau of Mines ROI 6204; Measurements of Surface Subsidence, San Manuel Mine, Pinal County Arizona, Johnson Soule,1963



Diagrams Abstracted From:
Tiobie, Thomas &Richards, San Manuel Mine, Magma Copper Co.
SME Mining Engineering Handbook. Vol. 1, Cummings, Given 1973

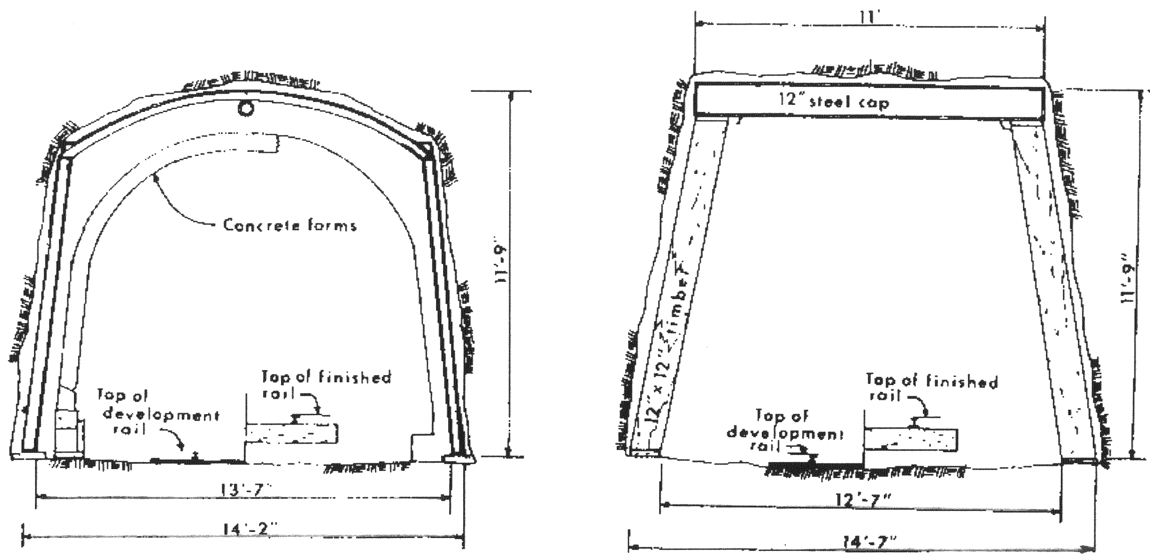


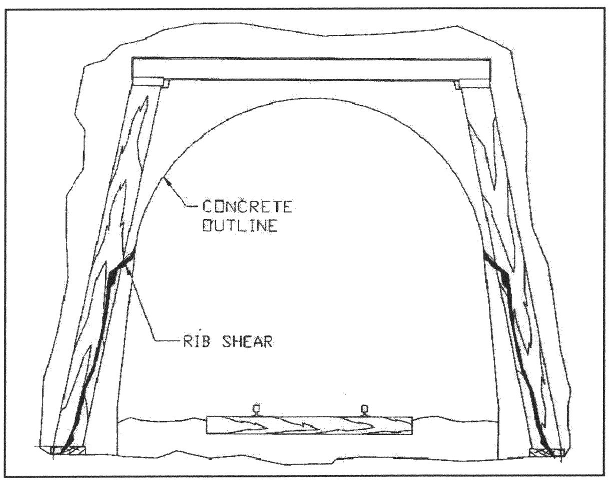
HYBRID DESIGN

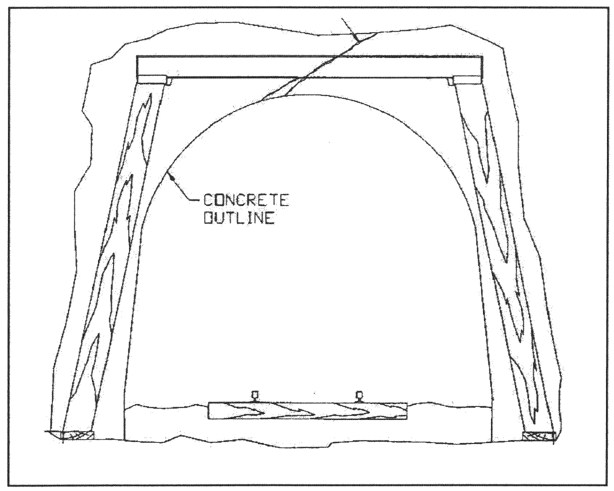


CONVENTIONAL DESIGN

Typical drift profile and ground support at San Manuel Mine







Typical rib shear in concreted haulage drift

Axial shear damage in typical haulage drift

Images courtesy Lou Sanbak

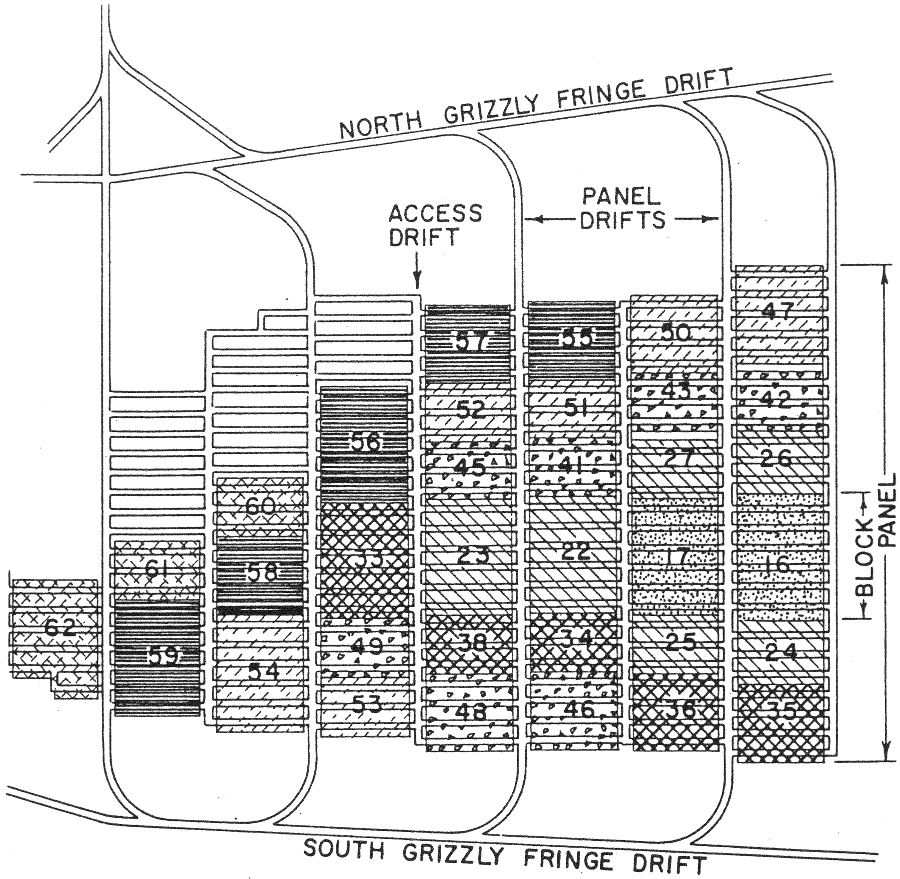


Fig. 12-207—Diagonal retreat panel caving by blocks, San Manuel mine.

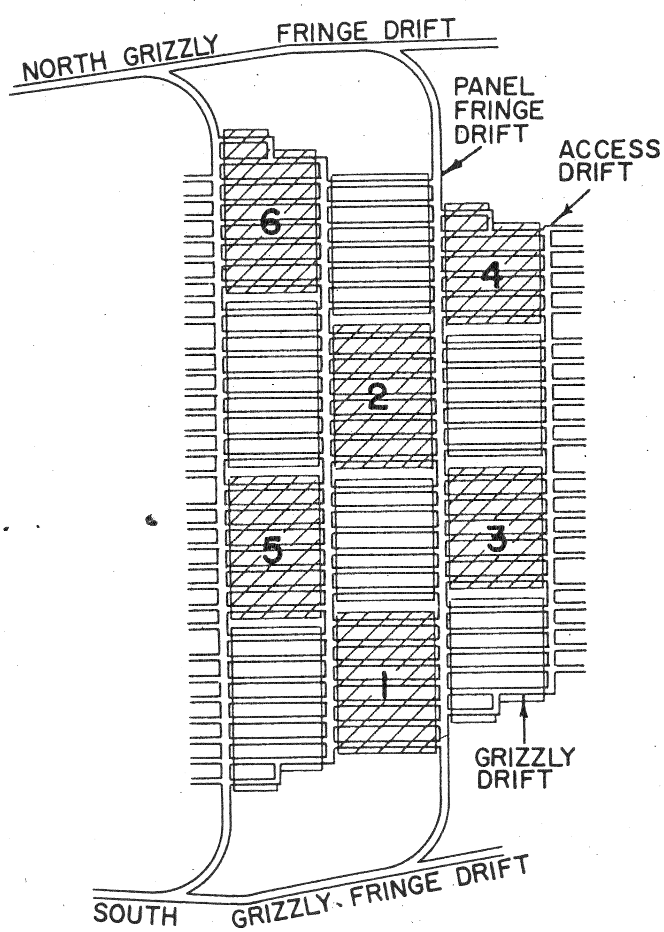


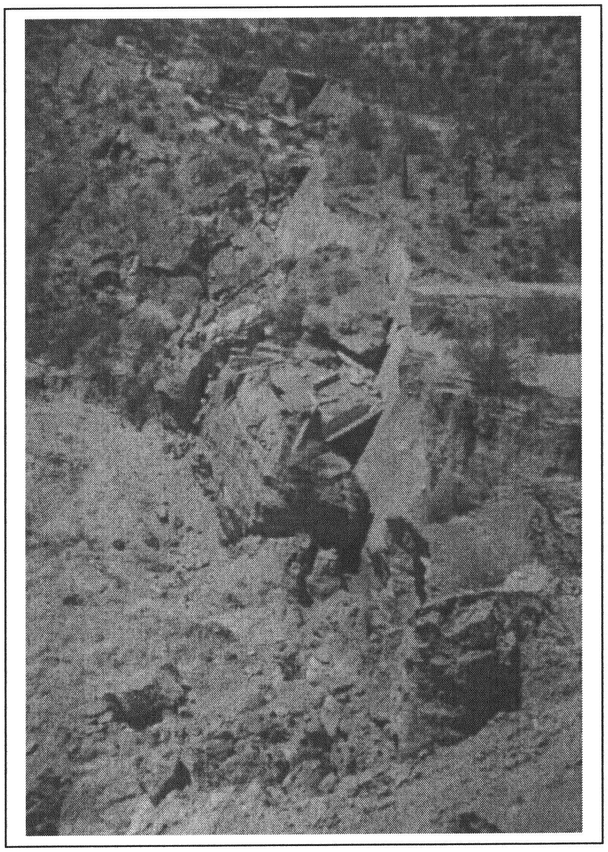
Fig. 12-206—Checkerboard sequence of block undercutting, San Manuel mine.

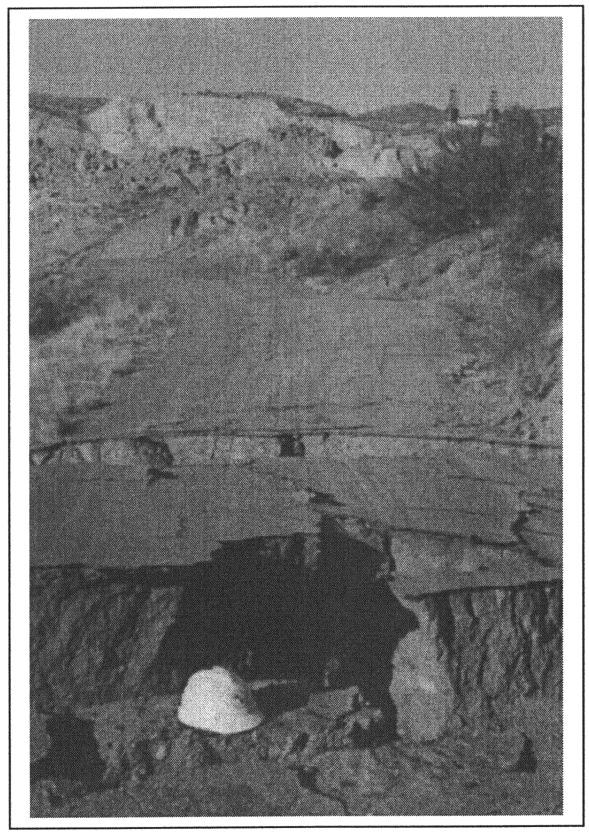
Diagrams Abstracted From:
Tiobie, Thomas &Richards, San Manuel Mine, Magma Copper Co.
SME Mining Engineering Handbook. Vol. 1, Cummings, Given 1973

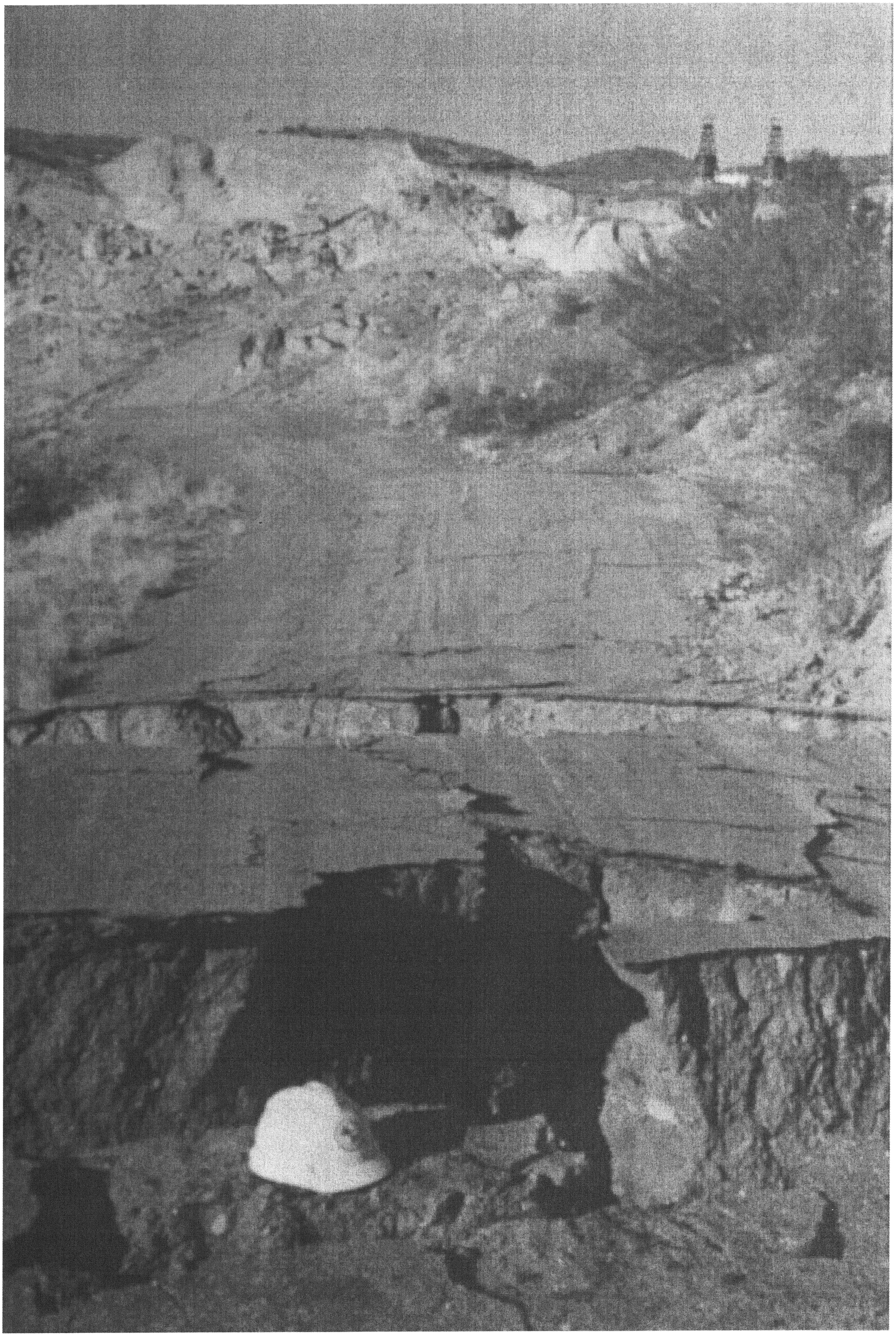
Roadway Damage

Photo images courtesy Allen Hatheway

The following images display the destruction of small bridge on the former aligment of SR 77, at the edge of subsidence basin above the south ore body in 1965. The other images illustrate the destruction of pavement structure in the old highway alignment.







Roadway Damage from Subsidence at San Manuel Mine

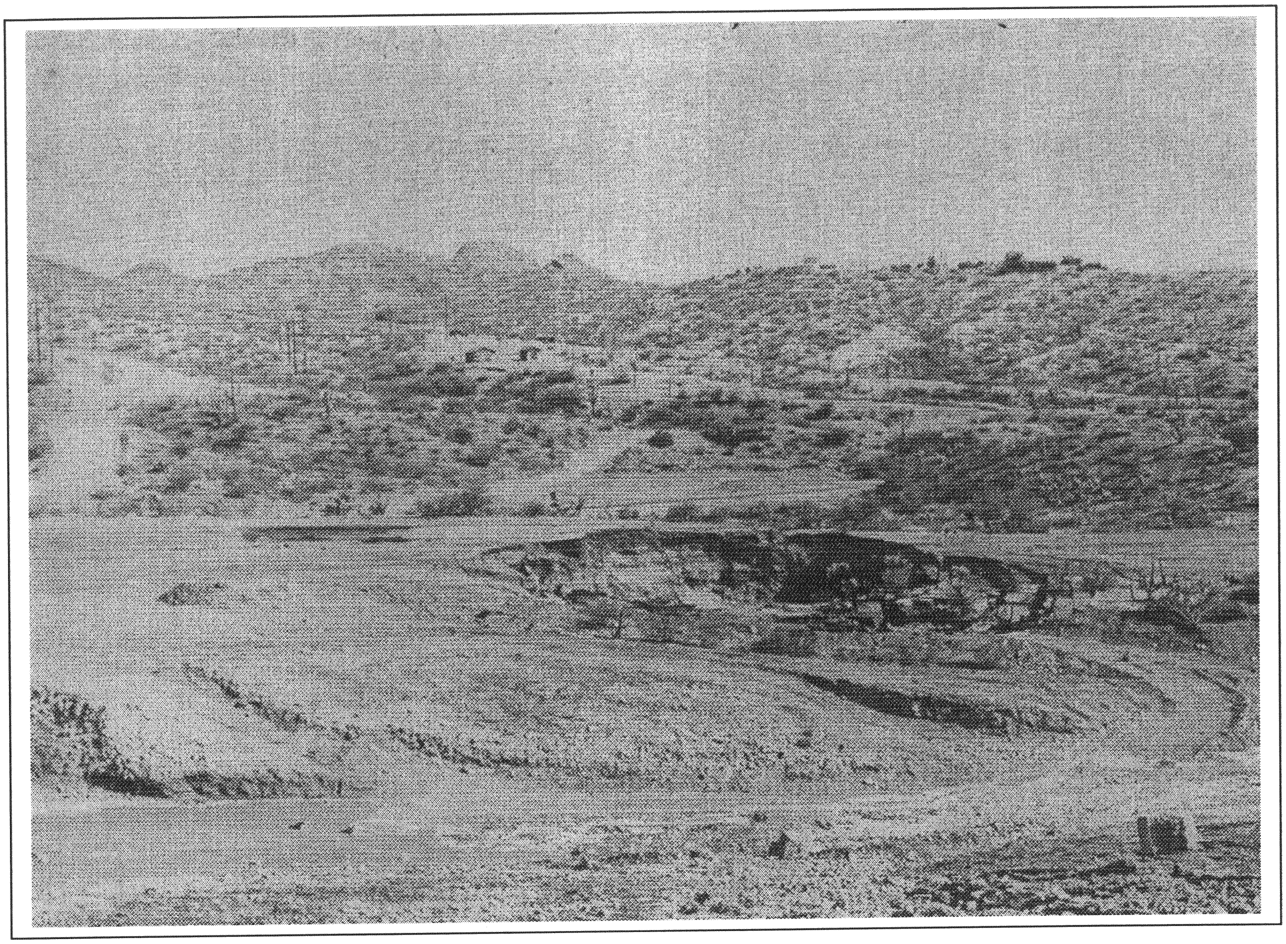
Photo Courtesy of Lou Sanback

SUBSIDENCE

At San Manueal

Photo Images Courtesy of L. A. Thomas, Allen Hatheway, and The Arizona Department of Mines and Mineral Resources & BHP Copper

The following sequence of Images illustrates the development of surface subsidence at the San Manuel   Mine in the period between 1956 and 1996.



First Subsidence - 1956

The initial breakthrough to the surface caused by draw from the 1415 level of the San Manuel Mine occurs on June 16, 1956 when an area about 100 feet in diameter holed through, with the "plug" dropping approximately 30 feet. The hole was located over the west side of Block 9-1, which had been in production for 135 days at the time of collapse.

Concentric tension cracks (visible in the photo) immediately formed around the hole. Vertical distance from the 1415 level to surface was 1120 feet.

View is looking northerly across on of the Red Hill housing areas, which was still occupied at the time. Tiger town site lies behind the ridge with the houses and the top of the Collins Glory Hole is visible as the twin peaked hills on the left-central skyline.

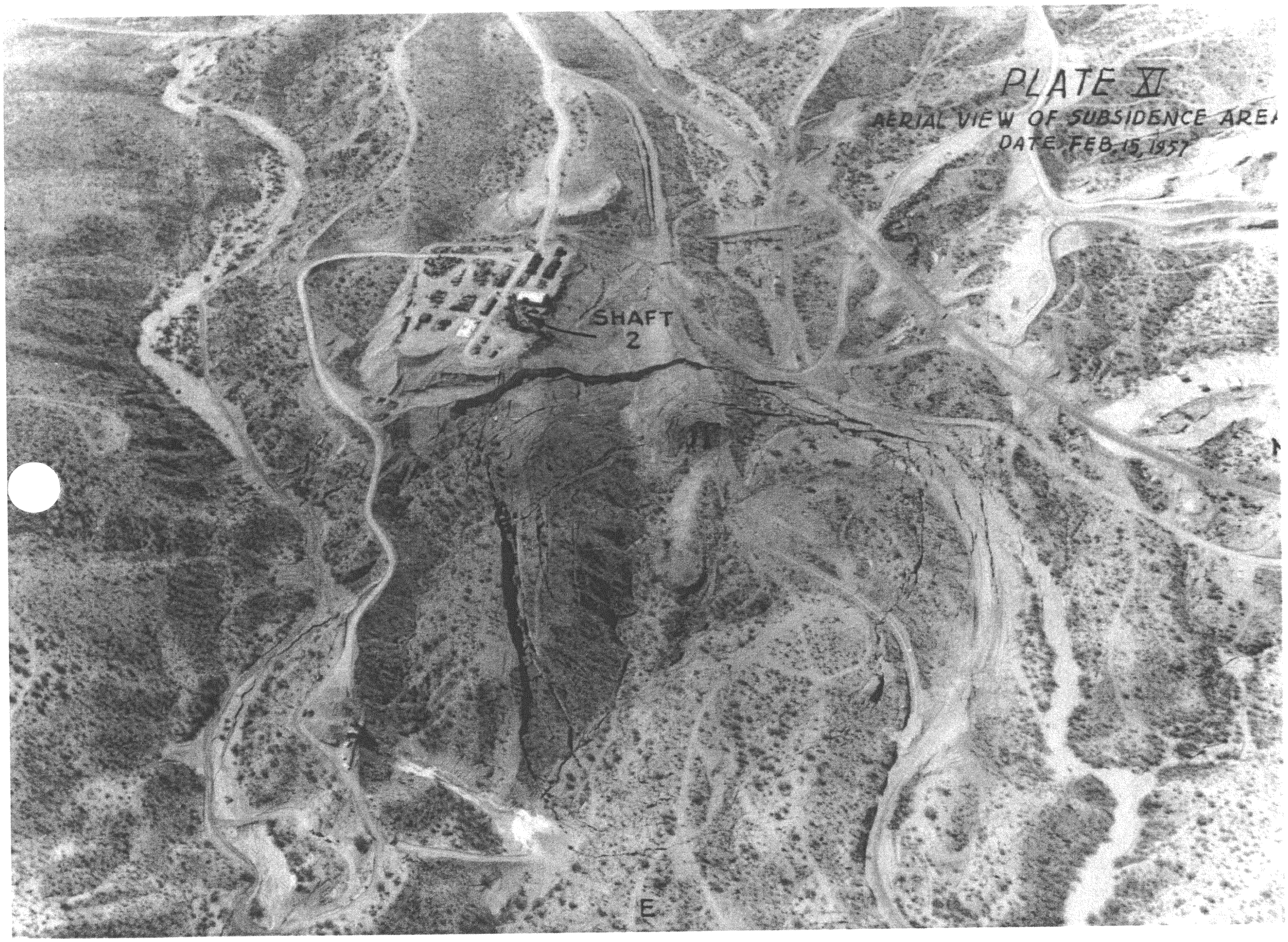
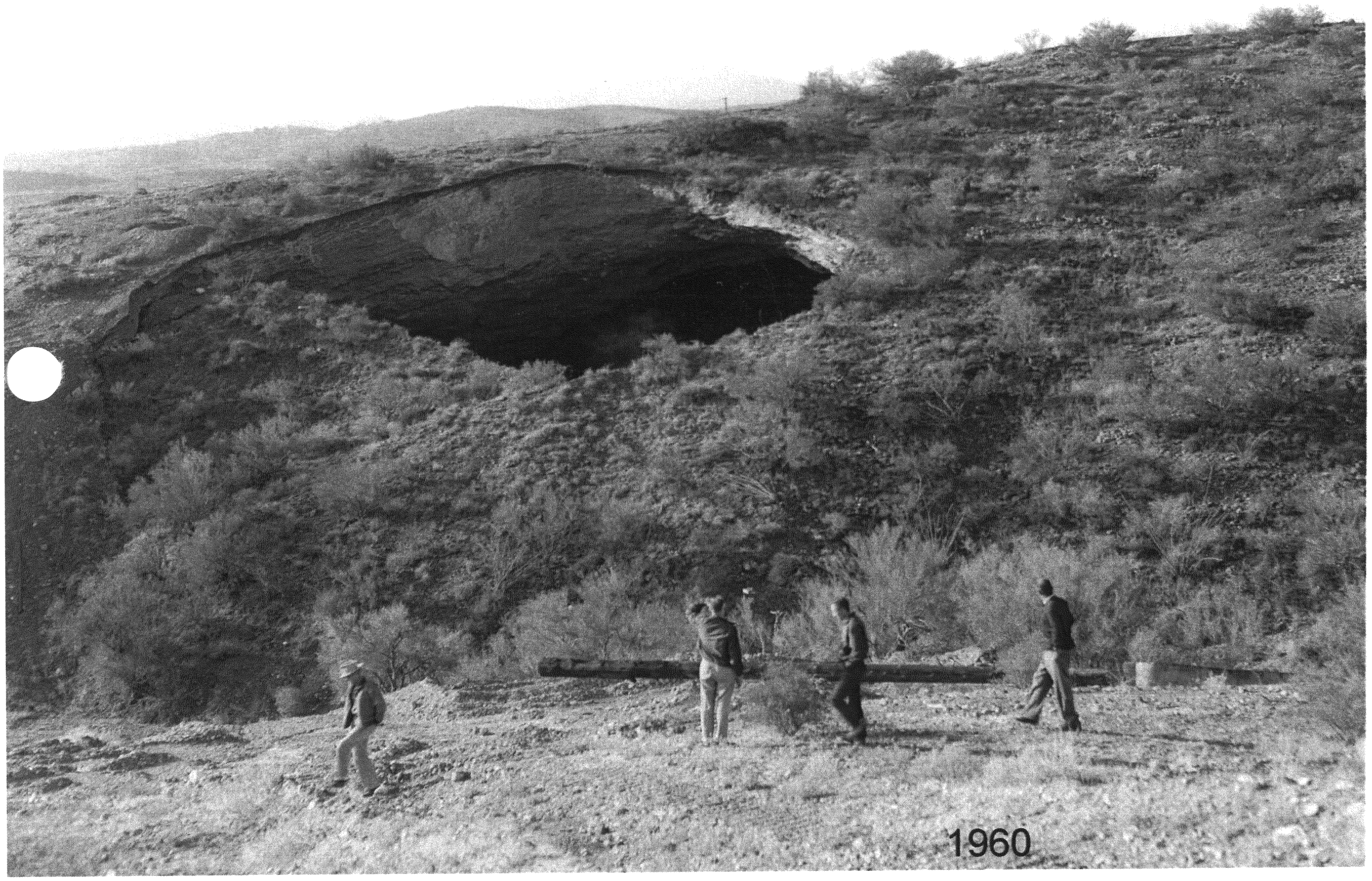
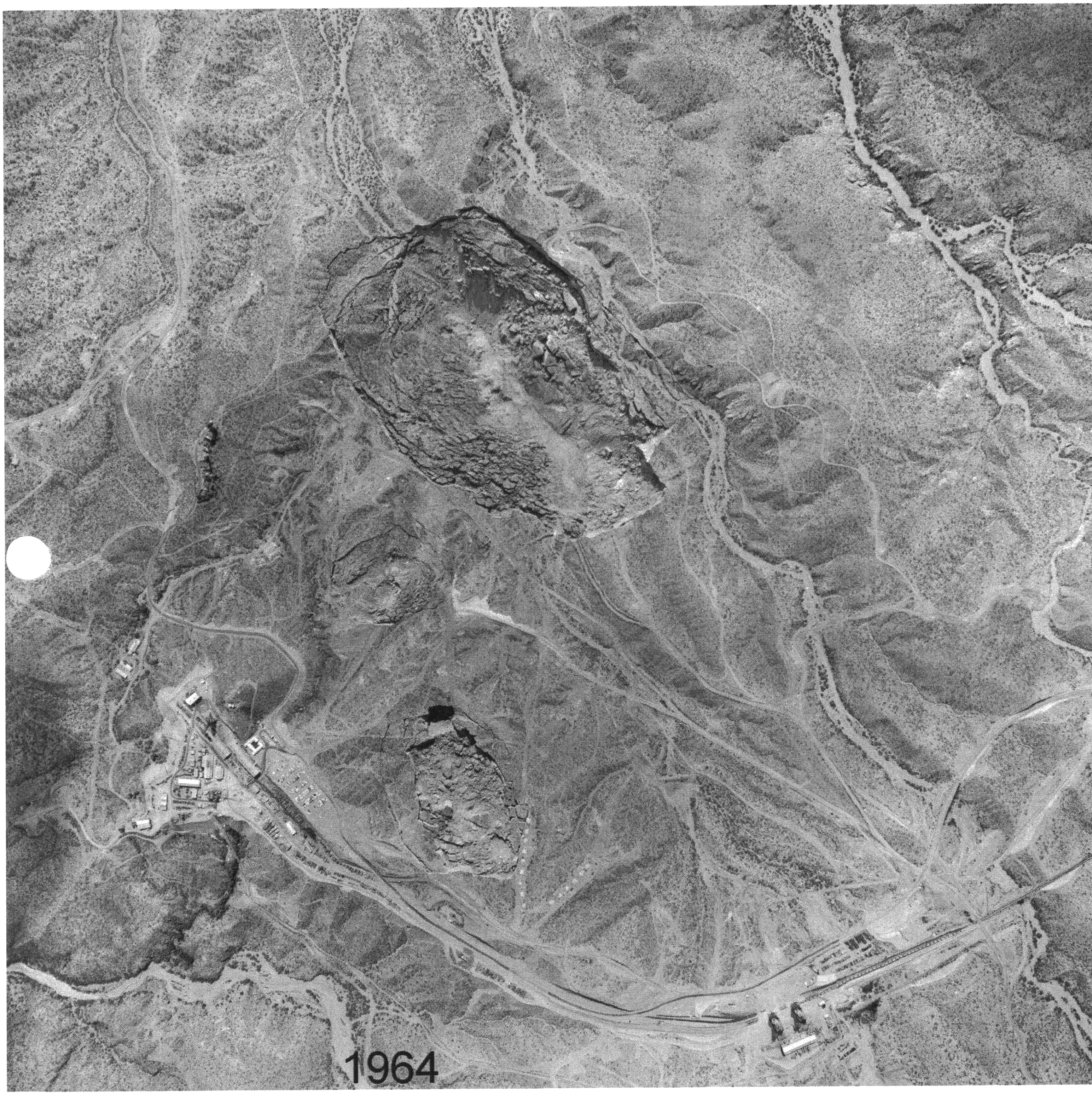
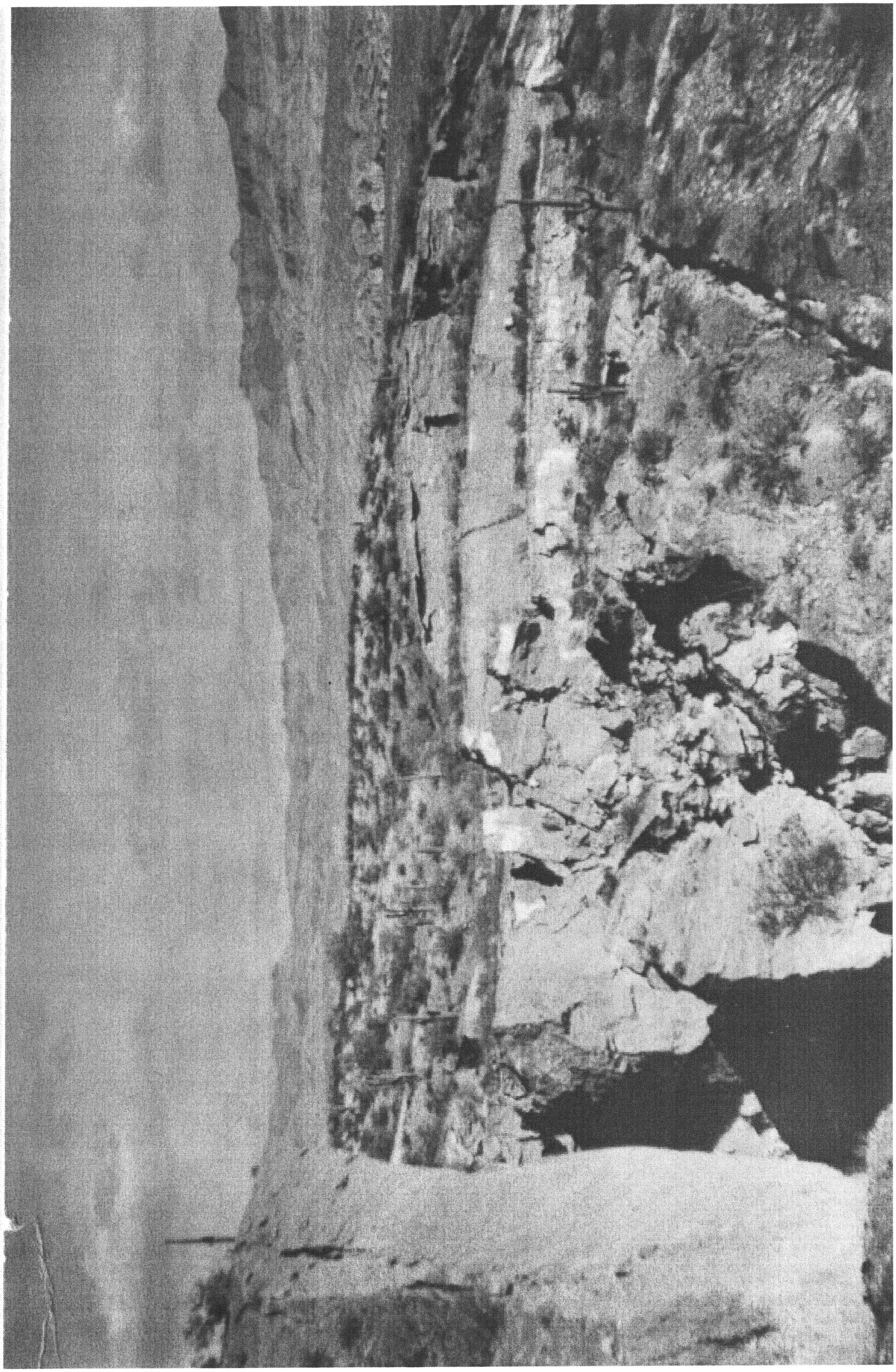


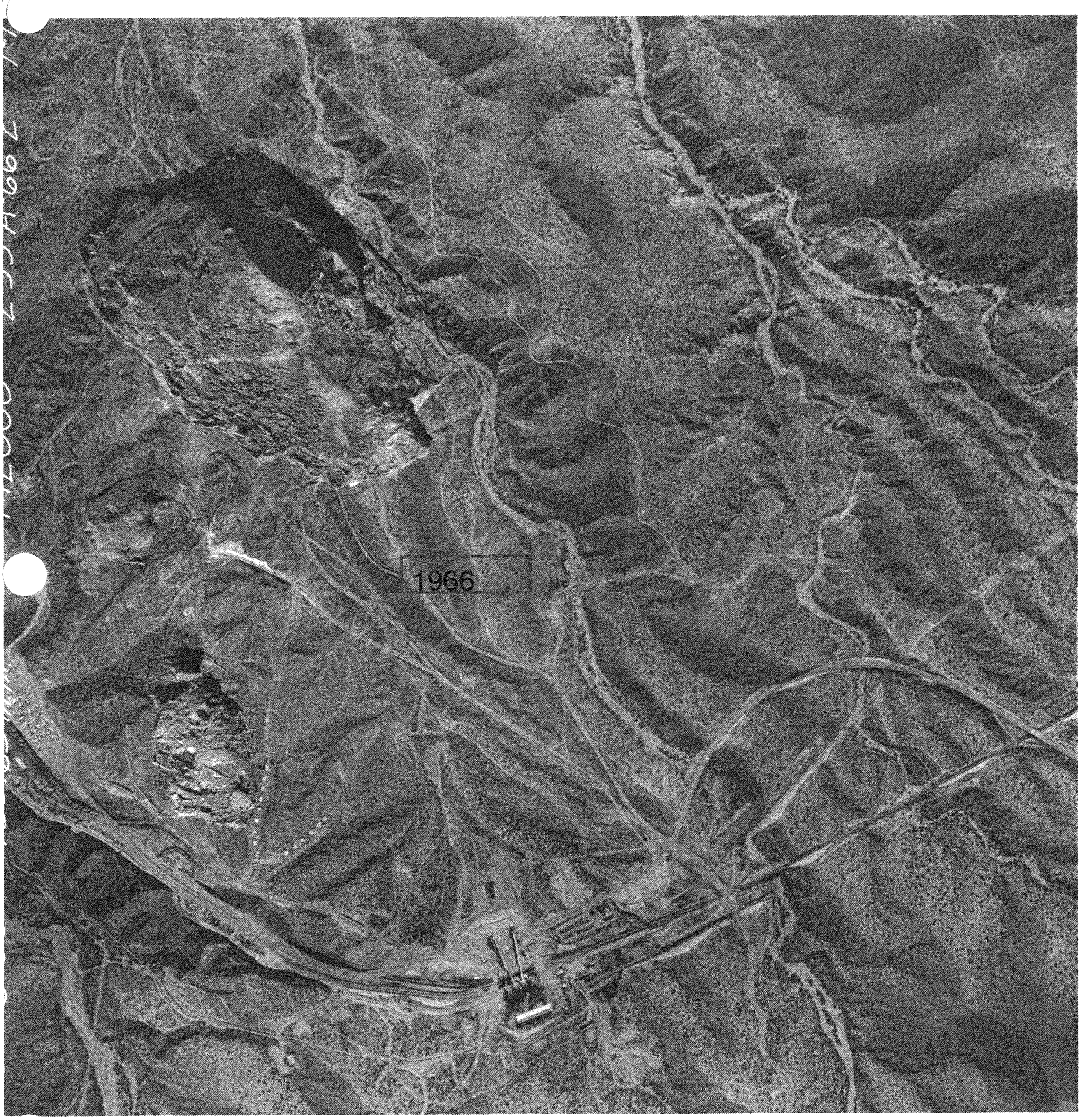
PLATE XI
AERIAL VIEW OF SUBSIDENCE AREA
DATE FEB. 15, 1957
SHAFT 2
E


1960


1964


1964




1966


1973


1983